NEDC et al. v USACE et al: (Case No.: 3:18-cv-00437-HZ)

Assessment of risks to human life and safety from proposed modifications to operations

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Glossary

Antecedent: In the context of this analysis, the precipitation and soil moisture conditions that precede an operational change, which can contribute to hillslope instability.

Hydrophobicity: A physical property of soils to repel water, which increases dramatically after wildfires, increase runoffs, and reduces hillslope stability.

Landslide: A broad term that reflects multiple ways (falling, toppling, sliding, spreading, or flowing) a hillslope can fail.

Ramping rates: The rate of increase or reduction of water releases, which are limited to protect life safety and to avoid stranding of organisms downstream.

Regulating outlet (RO): Outlets located at lower elevations in the dam that are used in drawing the reservoir down and for temperature or water quality management. ROs typically involve a set of sliding gates, with a "service" gate that is used for typical operations and an upstream gate used in emergency and maintenance operations.

Reliability: The probability that a system can achieve a specified target for a given set of conditions.

Rule curve: Also called guide curve. The relationship between the day of year and the intended/desired elevation of a reservoir, structured by vertical zones within the reservoir and seasonal objectives (flood storage, water conservation, etc.)

Seepage force: As water drains out of a saturated soil, it creates a pressure, called pore water pressure, between the grains that pushes soil grains apart and reduces soil stability

Unconsolidated: Loosely arranged sediment that is not cemented or strongly compacted and thus is easily eroded. In the context of this analysis, sediments deposited in reservoirs tend to be unconsolidated, whereas hillslope sediments tend to be more consolidated.

Executive Summary

In NEDC et al. v USACE et al., interim measures for reservoir operations were proposed by the Plaintiffs to address fish passage and water quality concerns while management and resource agencies undergo consultation. These interim measures include changes to the outlets used to release flows and to the timing and depth of refill. Measures also include recommendations for drawing down some of the reservoirs to lower levels and/or for extended periods. As requested by the Court, I have conducted a review of potential human life and safety risks associated with the proposed measures. This review does not consider potential conflicts with other operational objectives, including water supply, hydropower production, recreation, or meeting biological flow targets. This review also does not consider the biological or environmental effectiveness of the measures, relationships to USACE's interim operational measures or their operational authority, or a number of other factors outside of potential human life and safety risks.

The proposed operational measures were characterized (Table 2) into three types of measures: 1) changes in outlets but not discharges, 2) modified refill; and 3) reservoir drawdown. Each measure was considered for its potential contribution to three broad types of risks, all associated with flood risk downstream of the dam: 1) Downstream flooding from operational changes, 2) reservoir sediment instability, and 3) loss of flood control capability through impacts on outlet works and hydromechanical equipment (e.g. gates, turbines). Each measure was classified into three risk categories: 1) no appreciable risk, 2) minor or mitigatable risk, 3) high likelihood or consequence risk. The framing of risk is based on the assessment of both the likelihood and consequence of impacts to human life and safety in a qualitative way, relying on existing data, model simulations, peer-reviewed literature, inspection reports, and professional judgment. Technical justification for the risk ratings is provided in Section 3.2.

Key findings are broadly summarized by the types of risk below:

1. <u>Downstream flooding from operational changes.</u> None of the proposed measures are expected to increase directly flood risk to downstream communities as a result of increasing

water releases during critical flood management periods. Both parties recognize that USACE will prioritize flood risk management over the proposed operational measures.

2. Stability of reservoir sediments. Measures that result in the drawdown of reservoirs and changes in timing of refill have the potential to produce risks both within the reservoir and downstream if they contribute to substantial erosion of reservoir sediments and/or trigger landslides within the reservoir. While the risk associated with instability of reservoir sediments is generally low across the WVP projects, some measures may result in elevated risk. In particular, given the potential for erosion of sizeable volumes of reservoir sediments and for landsliding within Lookout Point reservoir during deep drawdown (MFW 1), further study would reduce uncertainties about the potential for sediment to exit the reservoir and contribute to localized flooding downstream of Dexter dam. Other measures proposing changes in reservoir refill or drawdown, including Detroit drawdown (NS1, Table 2a) and extended Fall Creek drawdown (MFW9, Table 2c) are found to have minor or mitigatable impacts associated with landslide susceptibility or the delivery of sediment to the downstream channel.

3. Loss of flood control capability. For most of the Plaintiffs' proposed measures, the primary risks generated by modifying which outlets are used to release water are associated with increasing wear and tear on the outlet works. Wear and tear may increase for gates, spillways, mechanical-electrical control systems, and the conduits through which water flows. The increased wear and tear under the proposed measures, particularly on the regulating outlets (ROs), will accelerate the timeline for maintenance and replacement. In addition, increased and varied use of the ROs and turbines should be coupled with regular inspection and monitoring. [redacted]

1. Introduction and scope of review

The scope of this evaluation reflects the expert order issued by Judge Hernandez, which limits the review to analysis of risks to human life and safety. The expert order explicitly identified the risks of loss of flood control capability, damage to the structural integrity of the dams, and riverbank collapse. Loss of flood control capability was qualitatively analyzed by considering the expected wear and tear on gates and turbines from more frequent and varied use. Damage to the structural integrity of the dam was considered qualitatively through potential dam failure modes. I evaluated riverbank collapse as the potential for the drawdown operations to destabilize sediments and hillslopes in the reservoir. Concerns about reservoir sediment stability relate to a) potential for downstream flooding resulting from the delivery of large volumes of reservoir sediments, and b) impacts to infrastructure (e.g. roads, buildings, a large dam) in the immediate vicinity of a reservoir resulting from landslide activity. In addition, I considered the potential for increases in flood risk for downstream communities associated with any proposed changes in the volumes and timing of flow releases.

My analysis of these risks is not quantitative. Qualitative risk assessments were considered adequate to support implementation decisions based on the potential for the measures to elevate human life and safety risks. In addition, analysis of the operations under a range of hydrologic scenarios would have unnecessarily delayed the legal process. As such, I have not conducted any modeling of reservoir operations, hillslope stability, or reservoir erosion. Instead, I relied on existing modeling efforts (e.g. OMET 2012), publicly-available data (e.g. DOGAMI 2020), peer-reviewed literature, publicly-available reports, inspection reports provided by the Defendants, and professional judgment.

I aimed to make no assumptions of how the proposed operations would be implemented. Supporting documents and declarations from the Plaintiffs and Defendants were very constructive in clarifying details of the proposed operations. I expect, but do not guarantee, that the analysis presented herein closely reflects the intended measures. In addition, I note that not all of the proposed remedies were evaluated. Only measures that have potential to modify the risks to human life and safety from flooding and sediment stability were evaluated.

Thus, measures associated with monitoring and coordination, among others, were not considered in this analysis.

Finally, at the recommendation of Judge Hernandez, I note that the scope of this analysis does not include analysis of any expected impacts of the proposed measures on compliance with Reasonable and Prudent Alternatives (RPAs) under the Biological Opinion (BiOp) (i.e. tributary and mainstem flow targets, USFWS 2008) or other environmental criteria and standards (i.e. temperature). In addition, this report does not provide comment regarding impacts on the generation of hydropower or on recreational opportunities. The USACE perspective on these tradeoffs is discussed in detail in the declarations from Askelson, Piaskowski, and Taylor, as well as in the USACE summary of modeling results for some of the proposed measures (OMET 2012). Additional impacts not directly related to human life and safety, such as those associated with drinking water quality or supply, are also not considered. I also do not comment on whether the proposed measures are within the current operating authority for the USACE. Analysis of the relationships of these measures to operating authorities are provided in the declaration of Askelson and in USACE (2012). Assessment of the expected benefits or costs of the proposed measures on fish or water quality is not included, nor is the relationships between the Plaintiff’s proposed measures and the interim measures the USACE has been conducting (See Piaskowski declaration for details on USACE interim measures).

2. Summary of the WVP and baseline reservoir operations

The Willamette River Basin (WRB) is a large tributary that drains north to the Columbia River, with a catchment area of 11,480mi^2. The basin drains a diverse landscape shaped by subduction tectonics, volcanism, flooding, and erosion. Throughout the basin, the Mediterranean climate results in highly seasonal water supply and demands. The long, wet winter and spring snowmelt produce runoff that historically flooded large areas of the Willamette tributaries and floodplains, resulting in significant loss of life and property. In response, a collection of 13 dams (Table 1) and revetments, known as the Willamette Valley Project (WVP), were constructed in the tributaries to reduce flood losses and augment summer flows. Thirteen ESA-listed species of salmon and steelhead are impacted by the WVP (NMFS 2008), with the Upper Willamette River Chinook at greatest risk of extinction. Through the consultation process that resulted in the 2008 BiOp, RPAs were established to protect the ESA-listed species, which included many proposed changes to infrastructure and operations at USACE reservoirs.

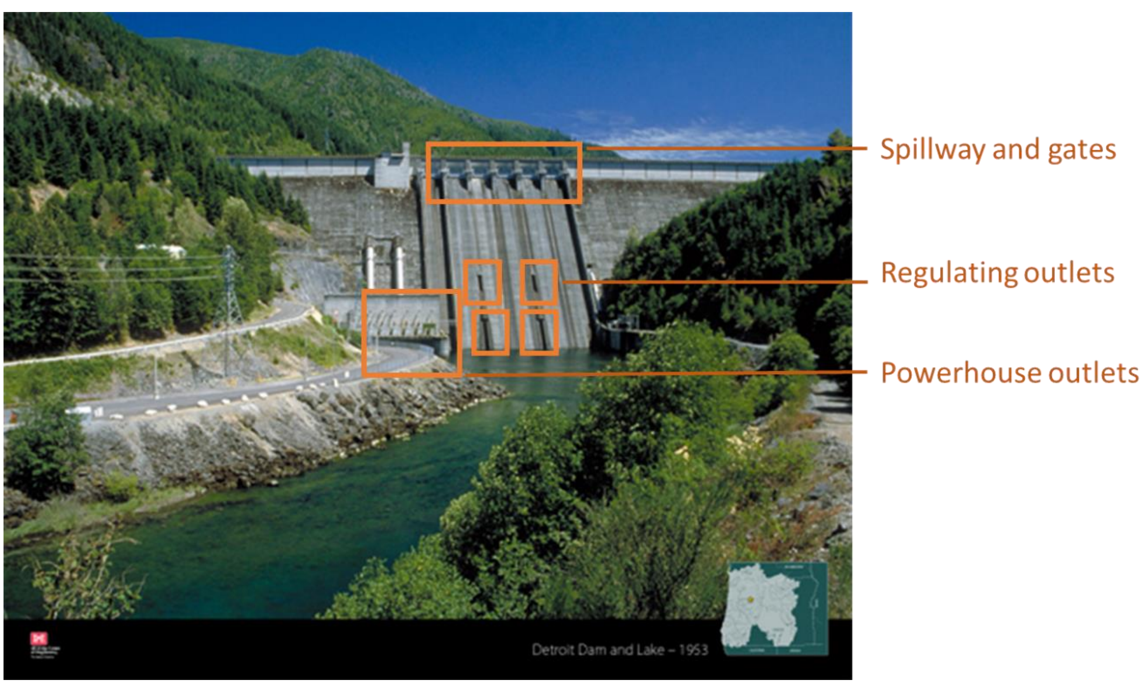
Table 1. Characteristics of WVP dams and associated reservoirs. These reservoirs represent a range of storage capacities, variability in the priority of releases, and the hydrogeology of upstream catchments (e.g., groundwater versus surfacewater dominated).

Dam name	Dam height (ft)	Dam material	Catchment size (mi^2)	Reservoir storage capacity @ full pool (kaf)
Big Cliff	191	concrete	449	4.7
Blue River	270	rockfill	88	89.5
Cottage Grove	95	earthen	104	32.9
Cougar	519	rockfill	207	200.0
Detroit	463	concrete	437	455.1
Dorena	145	rockfill	265	77.6
Fall Creek	205	rockfill	184	125.1
Fern Ridge	44	earthen	275	97.3
Foster	126	rockfill	492	60.8
Green Peter	327	concrete	277	428.1
Hills Creek	304	earthen	389	355.6
Lookout Point	276	earthen	991	456.0

The 13 federal multipurpose reservoirs in the WVP are operated as a system with the objectives of providing flood regulation, baseload and peaking hydropower production, recreation, fish and wildlife conservation, water supply, and water quality regulation. Regulating flood flows is the highest operational priority for determining reservoir releases, and the priority of other operating objectives varies by reservoir and circumstance. Operations for meeting flood regulation and water conservation storage priorities are set by a rule curve at each dam, which was established when the dam was authorized. In addition to operational priorities, releases are subject to constraints (e.g. ramping rates) and regulatory targets at downstream control points, including targets for flood elevations and biological flows. For example, April–October minimum flow targets were established under the 2008 BiOp (NMFS 2008) and that vary across months and based on water year type (i.e., abundant, adequate, insufficient, deficit).

At the level of individual reservoirs, water releases for meeting flows targets can be directed to different outlets (i.e., powerhouse, regulating outlet, spillway, Figure 1) to support different objectives, such as minimizing total dissolved gas (turbines), matching inflow temperatures (all outlets), and downstream passage (spillways and ROs).

Figure 1. Various outlets highlighted at Detroit reservoir. (Image source: USACE)



At the system level, because the places of concern (i.e. control points) are downstream of multiple reservoirs, operations of the thirteen reservoirs that are interdependent. Operations at multiple reservoirs can be influenced by a single control point (e.g., minimum flow for the Willamette at Salem, Oregon) and multiple control points can be influenced by a single reservoir (e.g. Detroit reservoir). As a result of these interdependencies, operational changes at any reservoir can impact other reservoirs in the system. Meeting flood and fish targets at downstream control points is accomplished through prioritization of storage and releases across the reservoirs.

Key challenges in operating the reservoirs are driven in part by the attempt to meet the diverse needs of all species, life histories, and stages of the salmonid life cycle in the basin (see G. Taylor's declaration for details), as well as operating for diverse and changing needs and values of residents in the basin (Jaeger et al. 2017). Further details on the operations of the reservoirs are provided in USACE's Standard Operating Procedures (USACE 2012), Askelson's declaration, among other documents, and are not repeated here in the interest of brevity.

3. Risks to human life and safety from proposed modifications

3.1 Summary of key findings regarding risks to human life and safety

The proposed operational measures were broadly characterized (Table 2) into three types of measures: 1) changes in outlets but not discharges, 2) modified refill; and 3) reservoir drawdown. Each measure was considered for its potential contribution to three broad safety impacts: Downstream flooding due to operational changes, reservoir sediment instability, and loss of flood control capability through impacts on hydromechanical equipment (e.g. gates, turbines). All three of these safety impacts were considered for their potential contribution to downstream flooding. First, operational changes were evaluated for their potential to result in more water being released during flood management periods. Second, I evaluated the potential for reservoir sediments to erode during drawdown and subsequently deposit downstream in sufficiently large volumes to increase localized flooding. Finally, I evaluated if and how increased and varied use of outlet structures could contribute to reduced, or complete loss of, flood control capability. In this last scenario, I considered how a failed gate or turbine could lead to uncontrolled water releases through a failed outlet or catastrophic overtopping during a high flow event.

Each proposed operational measure was classified into three risk categories for each potential safety impact: no appreciable risk, minor or mitigatable risk, high likelihood or consequence risk. The framing of risk is based on the assessment of both the likelihood and consequence of impacts to human life and safety. For example, in assessing risk of landslide hazards, both the likelihood of a landslide is assessed, as is the potential for loss of life as a consequence of a landslide occurring. In addition, specific proposed measures were relevant to specific safety impacts. For example, measures associated with refill and drawdown were evaluated for their impacts on sediment stability, whereas changes in outlets were assessed for flood control capability. Details of how measures were assessed are provided in Section 3.2, with greater detail provided on reservoir sediment stability due to the greater number of factors involved in assessing risk.

Downstream flood risk from operational changes. When considering only the effects of changing the volumes and timing of water releases, none of the measures are expected to directly result in elevated flood risk to downstream communities. Many of the proposed measures are not in conflict with flood operations, and for those where conflicts could arise, both parties acknowledge that USACE will prioritize flood risk management over the proposed operational measures.

Reservoir sediment instability. Measures that result in the drawdown of reservoirs and changes in the timing of refill have the potential to produce risks both within the reservoir and downstream if they contribute to substantial erosion of reservoir sediments and/or trigger landslides within the reservoir. The degree of risk from drawdown varies across reservoirs based on two key factors: 1) the local geology and infrastructure at risk, and 2) the depth and rate of the drawdown. While the risk associated with the instability of reservoir sediments is generally low across the WVP projects, some measures may result in elevated risk. As justified in Section 3.2, I find that further study is needed to verify that deep drawdown at Lookout Point (MFW 1, Table 2c) will not increase the likelihood of localized flooding downstream in response to the erosion of sizeable volumes of reservoir sediment or the likelihood of landsliding within the reservoir. Detroit drawdown (NS1, Table 2a) and extended Fall Creek drawdown (MFW9, Table 2c) was found to have minor or mitigatable impacts associated with landslide susceptibility or the delivery of sediment to the downstream channel.

Loss of flood control capability. For most of the Plaintiffs' proposed measures, the primary risks generated by modifying which outlets are used to release water are associated with increasing wear and tear on the outlet works, such as gates, spillways, control systems, and the conduits through which water flows. The increased wear and tear under the proposed measures, particularly on the ROs, will accelerate the timeline for maintenance and replacement. Identifying and addressing repair needs in a timely manner is critical to avoiding catastrophic failure of outlet works, which typical occurs in response to the accumulation of many small, but interacting, incidents, as well as human factors. In addition, taking outlets and dams offline for more frequent repair and maintenance will reduce the frequency that the

system can meet the project objectives or conduct other operations (e.g. temperature management, meeting minimum flows).

[redacted]

Table 2a. Summary of proposed measures and their potential impact on downstream flooding, reservoir sediment stability, and hydromechanical equipment: North Santiam, South Santiam.

		Interim measures		Safety impacts		
ID	Basin	Short description	Type of measure	Downstream flooding	Reservoir sediment stability	Loss of flood control
NS1	N. Santiam	Detroit: Drawdown (Nov-Dec)	drawdown		landslide susceptibility	[redacted]
NS2		Detroit: Regulating outlets at night	same flow, different outlet			
NS3		Detroit: 1/2 spillway flows at night	same flow, different outlet			increased wear and tear
NS4		Detroit: Use turbines for total dissolved gas	same flow, different outlet			increased wear and tear
NS5		Big Cliff: Spread spill	same flow, different outlet			increased wear and tear
NS6		Big Cliff: Use turbines for total dissolved gas	same flow, different outlet			increased wear and tear
SS1	S. Santiam	Green Peter: spillway	same flow, different outlet			increased wear and tear
SS2		Green Peter: Use of fish horn	same flow, different outlet			fish horn not functional
SS3		Green Peter: Temperature operations	same flow, different outlet			
SS4		Foster: Spillway operations	same flow, different outlet			increased wear and tear
SS5		Foster: Delayed refill	modified refill		landslide susceptibility	
SS6		Foster: Temperature operations	same flow, different outlet			increased wear and tear

no appreciable risk
minor or mitigatable risk
high likelihood or consequence risk

Table 2b. Summary of proposed measures and their potential impact on downstream flooding, reservoir sediment stability, and hydromechanical equipment: South Fork McKenzie.

		Plaintiffs' proposed measures		Potential safety impacts		
ID	Basin	Short description	Type of measure	Downstream flooding from operations	Reservoir sediment stability	Loss of flood control
McK1	South Fork McKenzie	Cougar: Reduce max refill	modified refill			
McK2		Cougar: Early drawdown	drawdown			
McK3		Cougar: Early and deeper drawdown with outlet change	drawdown + same flow, different outlet		landslide susceptibility	
McK4		Cougar: Delay refill	modified refill			
McK5		Cougar: Regulating outlets during spring	same flow, different outlet			increased wear and tear

no appreciable risk
minor or mitigatable risk
high likelihood or consequence risk

Table 2c. Summary of proposed measures and their potential impact on downstream flooding, reservoir sediment stability, and hydromechanical equipment: Middle Fork Willamette.

		Interim measures		Safety impacts		
ID	Basin	Short description	Type of measure	Downstream flooding	Reservoir sediment stability	Loss of flood control
MFW1	MF Willamette	Lookout Point: Early and deeper drawdown	drawdown		reservoir erosion, landslide susceptibility	
MFW2		Lookout Point: Regulating outlets for temperature	same flow, different outlet			[redacted]
MFW3		Lookout Point: Regulating outlets during drawdown	same flow, different outlet			[redacted]
MFW4		Lookout Point: Prioritize refill and spring spill	Modified refill			
MFW5		Lookout Point: Ungated spring spill	same flow, different outlet			increased wear and tear
MFW6		Dexter: Fall spill	same flow, different outlet			increased wear and tear
MFW7		Dexter: Spring spill	same flow, different outlet			increased wear and tear
MFW8		Dexter: Spread spill	same flow, different outlet			increased wear and tear
MFW9		Fall Creek: Extended drawdown	drawdown			
MFW10		Fall Creek: Regulating outlets for lower spring and summer pool	Increase spring releases			increased wear and tear

no appreciable risk
minor or mitigatable risk
high likelihood or consequence risk

3.2 Technical justification for interpretation of risk

3.2.1 *Downstream flood risk from operational changes.*

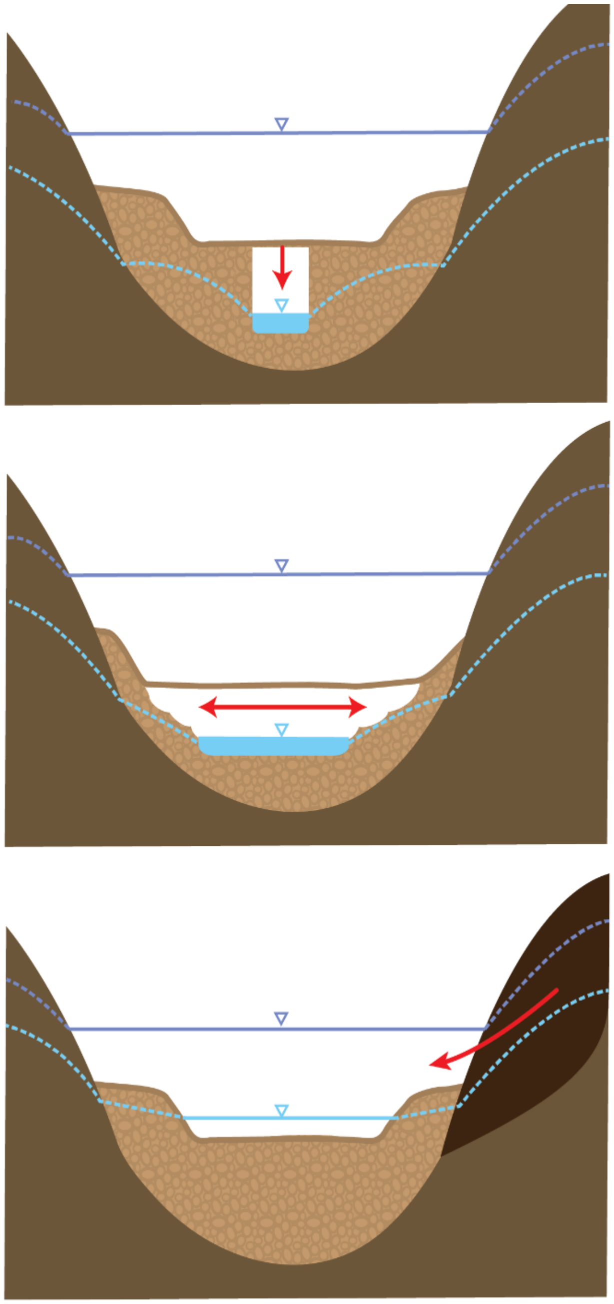
For assessing the impact of changing the timing and volumes of water releases on downstream flood risk, I relied on my own working knowledge of the system based on prior modeling of the reservoir operations (Tullos et al. 2020, Jaeger et al. 2017, Danner et al. 2017, Mateus et al. 2016a, Mateus et al. 2016b) and on the declarations provided by the Plaintiffs and Defendants. In addition, for 11 of the 27 operational measures reviewed, prior modeling studies (OMET 2012) verified that the proposed (or very similar) operational scenarios would not result in elevated flooding downstream (Appendix 2). A quantitative and comprehensive analysis of flood risk would evaluate the effects of changing operations on flood depths downstream, and translate those depths into losses based on the elevation of structures, heights of levees, etc. However, given that the proposed changes are not expected to increase downstream flood depths, a comprehensive flood risk analysis was not conducted.

The proposed measures are not expected to increase flood risk to downstream communities as a result of: 1) a lack of conflict between proposed measures and flood management, and 2) prioritization of flood management over environmental management. For the measures where increased releases are expected (e.g. MFW1 - Deep drawdown at Lookout Point), it is expected that USACE will operate the reservoirs to minimize downstream flood risk. As a result of prioritizing flood management, it may not be feasible to fully execute the proposed operations every year. However, the majority of the measures are not in conflict with the objective of storing flood flows and thus, independent of operational priority, would not be expected to impact flood operations or risk.

3.2.2 *Stability of reservoir sediments*

Background on reservoir sediment stability. Drawing a reservoir down can lead to the mobilization of sediment from three key mechanisms (Figure 2): 1) Vertical erosion of reservoir sediments, 2) lateral erosion of reservoir sediments, and 3) hillslope failures that produce landslides. The first two processes are associated with the erosion and movement of

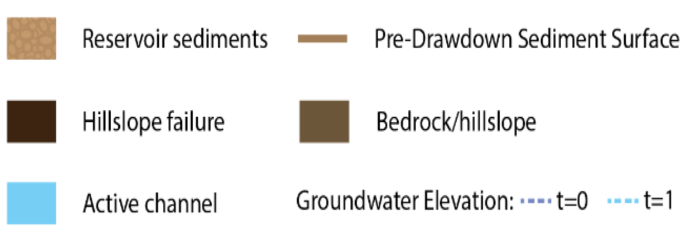
Figure 2. Summary of processes related to reservoir sediment stability and the delivery of sediment to downstream reaches. Red arrows indicate the direction of sediment movement.



1) Vertical erosion, also known as incision, occurs as a reservoir water elevation drops and the reservoir regains the slope of the former river. The erosion process lowers the streambed by mobilizing grains on the surface of the channel as a result of concentrated hydraulic forces.

2) Lateral erosion: Channel widening occurs as the incising channel creates steep, unstable banks prone to bank failure. Lateral erosion can regularly contributes more to sediment flux from reservoirs than vertical erosion during and following drawdown (Cui et al. 2019).

3) Hillslope failure: During drawdown, the hillslope becomes unstable as water seeps from the valley walls and as the reservoir water no longer buttresses the toe of the slope. The rate and depth of drawdown relative to how quickly the soils can drain, is a key factor in whether landslides will be triggered. Of the three sediment processes, landslides have the potential to contribute the largest volumes of sediment to the downstream channel, as well as damage local infrastructure.



sediments deposited in the reservoir, while the third process contributes new sediment to the reservoir from the adjacent hillslopes. In reality, these three sediment mobilization processes are coupled. Vertical erosion often leads to lateral erosion by producing oversteepened channel banks (Doyle et al 2002), and the erosion of sediments that buttress the bottom (i.e toe) of a hillslope can reduce hillslope stability and contribute to landslides (Levy et al. 2012).

The production of sediment from the first two mechanisms, vertical and lateral erosion of reservoir sediments, has been observed at many drawdowns (Major et al. 2017). These processes occur when any part of the reservoir is lowered to river level (i.e. no ponded water), which can occur in the upper portion of the reservoir even if water is still ponded near the dam. These unconsolidated, loose reservoir sediments, deposited in the reservoir over decades, can be highly mobile when the water surface slope of the reservoir approaches the valley slope, a condition that occurs during a drawdown that lowers the reservoir water elevation to the streambed. Conceptually, this is the condition of the reservoir acting like a river again, and it can occur in just the upper portions of a reservoir during partial drawdowns, which leave a pool of water near the dam (i.e. residual pool). In this case of partial drawdown, much of the eroded sediment is only carried as far as the remaining reservoir pool, where it is trapped. While the smallest-sized sediments will be transported through the outlets to the downstream channel, this suspended sediment tends not to deposit in the channel and thus is not likely to contribute to downstream flooding. In cases where an entire reservoir has been drawn down to the streambed, the volume of fine sediment produced by vertical and lateral erosion can contribute to the temporary degradation of water quality and habitat downstream under some circumstances (Foley et al. 2017). However, the depths of sediment deposited downstream are generally not enough to appreciably increase flood risk (Tullos et al. 2016). I note that cases do exist where downstream flood risk was elevated by the release of large volume of sediment, particularly when large (i.e. coarse) sediment was released (Warrick et al. 2015). A worst-case scenario for elevated downstream flood risk from reservoir sediments is the case with a deep drawdown of the entire reservoir to its streambed that produces the movement of large volumes of large (i.e. coarse) material, such as sand and gravel. What is more likely for most of the WVP projects, which do not involve complete drawdown and for which small (i.e. fine)

sediment comprises the majority of sediments in the reservoir, is that mobilized sediment will mostly stay in suspension and not appreciably impact downstream flood risk.

Instead, within the WVP, substantial risks to human safety are more likely to occur if reservoir drawdown contributes to the instability of hillslopes. While not frequent, history has demonstrated how changing water elevations in reservoirs can lead to hillslope failures in reservoirs around the world (Morgenstern 1963, Jones 1981, Zhong 1990, Viratjandr and Michalowski 2006, Zhan et al. 2006, Sun et al. 2017, Zhou et al. 2020). Landslides tend to generate much larger volumes of sediment than vertical or lateral erosion, and can produce highly destructive waves (e.g. Lake Roosevelt, 1940s-1950s) and catastrophic loss of life (e.g. Vajont Dam, 1963). It is my understanding that the type of catastrophic loss of life that occurred at Vajont Dam, which was produced by a landslide-driven wave (i.e. seiche) that overtopped the dam, is unlikely in the Cascade range because the large block failures that produce those waves are not common. Instead, my analysis focused on whether drawdown could increase likelihood of shallow hillslope failures and slow-moving earthflows, both of which occur more commonly in the Cascades and can produce large volumes of sediment. The consequences from these hillslope failures can include damage to local infrastructure (e.g. roads, buildings, railroads), restricted access to the dam for operating outlets and inspection of project structures, and erosion of new sources of sediment that could fill downstream channels and increase flooding.

Hillslope failures that produce shallow slides and earthflows (hencerforth *landslides*) can occur both as reservoirs are refilled and as they are drawn down (Jones 1981, Zhong 1990). During refill, submerging and saturating the toe of a hillslope can lead to instability and landsliding. During drawdown, hillslope failures occur when the force of water seeping out of the pore spaces between sediment grains, in combination with the weight of the soils, exceed the frictional forces that resist the movement of soil blocks (Viratjandr and Michalowski 2006). In reservoirs, another important factor is the benefit of the reservoir water buttressing the toe of the hillslope. Drawdown removes the confining pressure of the water that helps hold the hillslope in place, and the loss of that buttress can lead to movement of the hillslope.

In the Pacific Northwest, landslides tend to occur during the months with the greatest precipitation (e.g. November to February) because soils are already saturated, and thus heavy and lubricated for sliding. For example, the February 1996 flood produced 36 documented landslides in areas in and around reservoirs across the WVP (DOGAMI 2020). Seven of those landslides occurred in Detroit reservoir. The February 1996 flooding and landsliding occurred during and following an intense storm that dropped 12 to 27 inches of warm rain in the mountains over four days. This particular event was preceded by several weeks of high rainfall that had already saturated the soils and led to extreme flooding of up to 200-year recurrence interval in some areas. In addition to the triggering of new landslides as described above, reservoir drawdown can expose historical landslide material that has been stored in the reservoirs to erosion by the river flowing through an empty reservoir.

Thus, landslide susceptibility is primarily driven, and mapped (DOGAMI 2020), based on a combination of geologic features and the steepness of hillslopes, as well as the antecedent moisture in the hillslopes from precipitation in the preceding weeks to months. Based on the underlying geology of the basin, the hillslopes draining into most reservoirs in the WVP have elevated landslide risk and have produced landslides when the soils are adequately saturated. For example, between 1996-1997, agencies (e.g. USFS, ODOT, FEMA, local public works) mapped 12 landslides in areas surrounding Cougar reservoir, 61 landslides in areas surrounding Detroit reservoir, 15 in areas surrounding Fall Creek, 19 in areas surrounding Foster, and 21 in areas surrounding Lookout Point. As the maps in Figures 3-5 and 8-9 demonstrate, not all of these slides were along the reservoir shorelines. This context is relevant only to illustrate the susceptibility of the slopes in these areas to failure, independent of conditions in the reservoir.

In addition to characteristics of the landscape, the rate and depth of reservoir drawdown can exert a strong influence on the stability of reservoir sediments. Deep drawdowns can be problematic because the seepage force (i.e. positive pore water pressure) mentioned above is greatest when there is a large difference between the reservoir elevation and the elevation of the groundwater in the hillslope. Seepage forces can also be high during rapid drawdown, where the reservoir water level is lowered much faster than the reservoir sediments and hillslopes can drain. This leads to an “undrained” soil condition, where water is

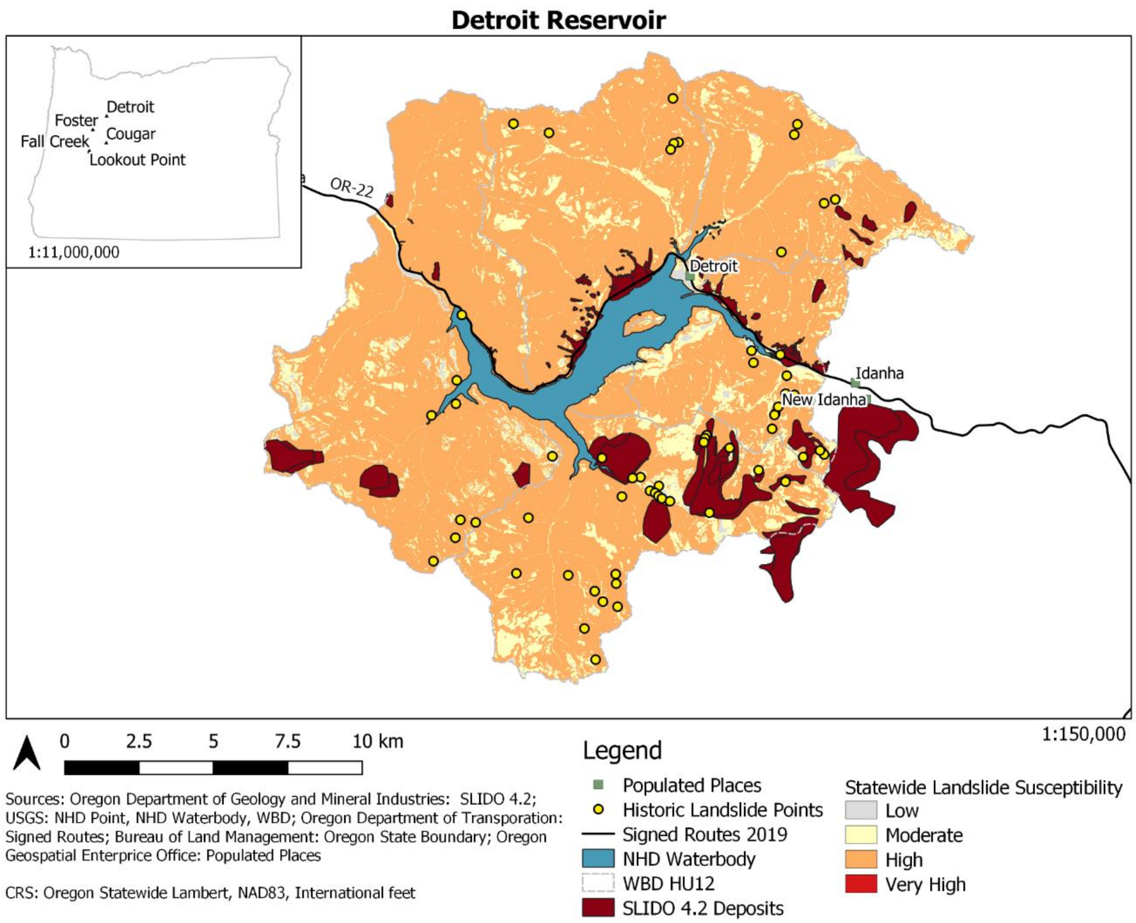
still stuck between the pores and thus friction between grains does not help to stabilize blocks of soil. The result is heavy, lubricated soil blocks that are ready to move and are no longer buttressed by the force of the reservoir water against them. As a result, slow drawdown operations that allow soils to drain and minimize the difference between the groundwater and reservoir elevations generally minimize the instability of reservoir sediments (Randle and Bountry 2017).

Evaluation of proposed drawdown measures on reservoir sediment stability. Based on the above conceptual framework, each of the drawdown and refill scenarios were evaluated for their impacts on reservoir sediment stability. For each measure, I considered the likely processes to be triggered (vertical erosion, lateral erosion, landsliding), the potential volume of sediment that would be transported downstream by those processes that could contribute to downstream flooding, and the potential for infrastructure or life loss as a result of landsliding.

<u>Early drawdown at Detroit (NS1).</u> Achieving the proposed early drawdown at Detroit reservoir would be accomplished by earlier and/or faster drawdown in the fall. Faster drawdown could contribute to issues of reservoir sediment instability. The sediments in Detroit reservoir are composed primarily of fines and sands (McMillan 2018), which are particularly vulnerable to slope failure and vertical and lateral erosion upon rapid draining. I was unable to find documentation on prior drawdowns at Detroit reservoir to evaluate whether an accelerated rate may lead to substantial mobilization of sediments, but I suspect that the volume would not be extreme. However, landslide susceptibility introduces some additional risk to changing drawdown operations at Detroit. Even prior to 2020, most of the surrounding area was mapped fairly contiguously as “high” landslide susceptibility and multiple prior landslides have been mapped along the shore (Figure 3). In addition, the 2020 Beachie Creek fire burned approximately half of the shoreline around the reservoir. Wildfires are known to increase landslide risk in subsequent years as a result of the loss of vegetation and post-fire hydrophobicity of the soils (Shakesby and Doerr 2006). The combination of potential for reduced stability of reservoir sediments, increased landslide risk from the Beachie Creek fire,

the adjacency of Highway 22, and an accelerated drawdown rate at Detroit under NS1 results in a rating of the measure as *minor or mitigatable risk*. To mitigate the risk of destabilizing reservoir sediments, early drawdown should be achieved by starting drawdown one month earlier rather than an accelerated rate of drawdown, though other tradeoffs are expected with an earlier drawdown of the reservoir.

Figure 3. Landslide susceptibility at Detroit reservoir. Data source: DOGAMI (2020). See Appendix 1 for summary of methods for assessing landslide susceptibility.

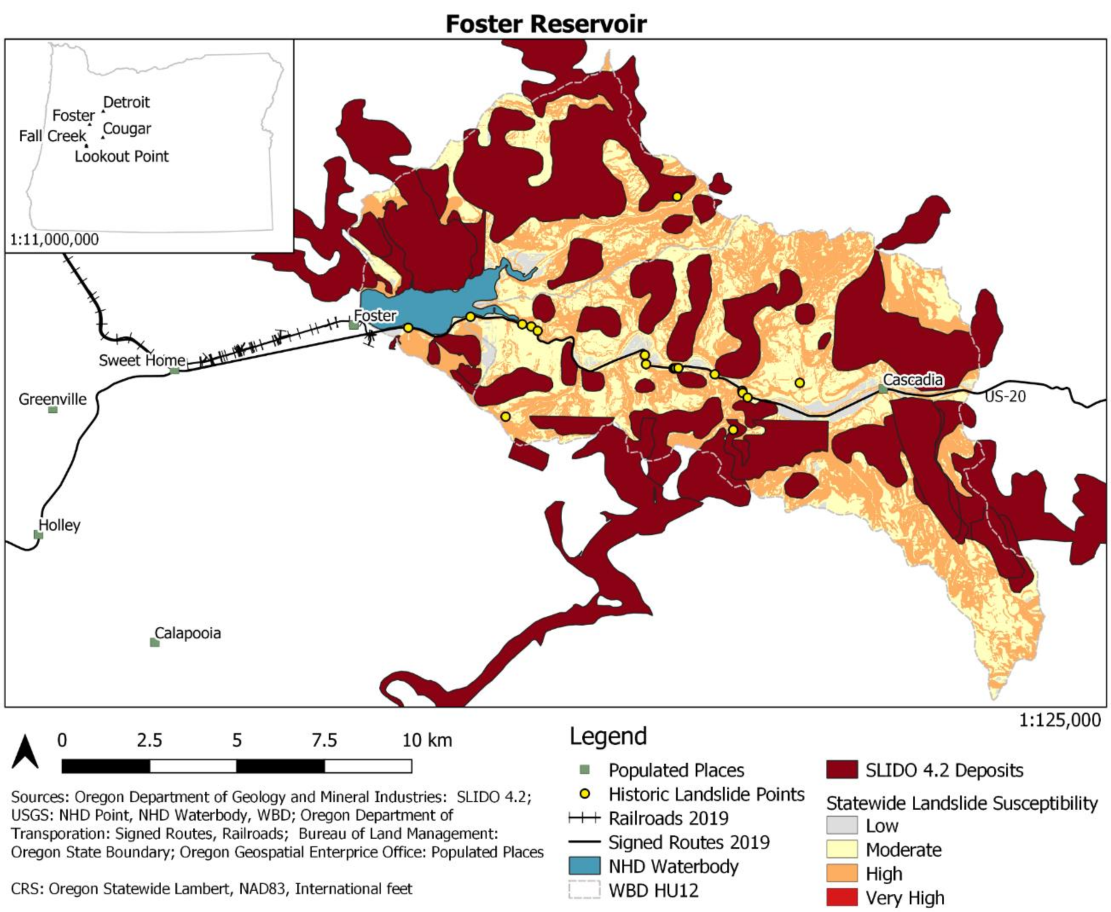


<u>Delayed refill at Foster (SS5).</u> The proposal to delay refill at Foster reservoir is unlikely to significantly elevate instability in the reservoir sediments. Keeping the reservoir at minimum conservation pool through May 15, rather than beginning refill February 01, may result in some increased erosion in the upper portions of the reservoir as spring rains and snow melt runoff

enters the reservoir. However, the reservoir pool will likely trap most of the mobilized sediment and/or small-sized sediment will pass through downstream reaches in suspension.

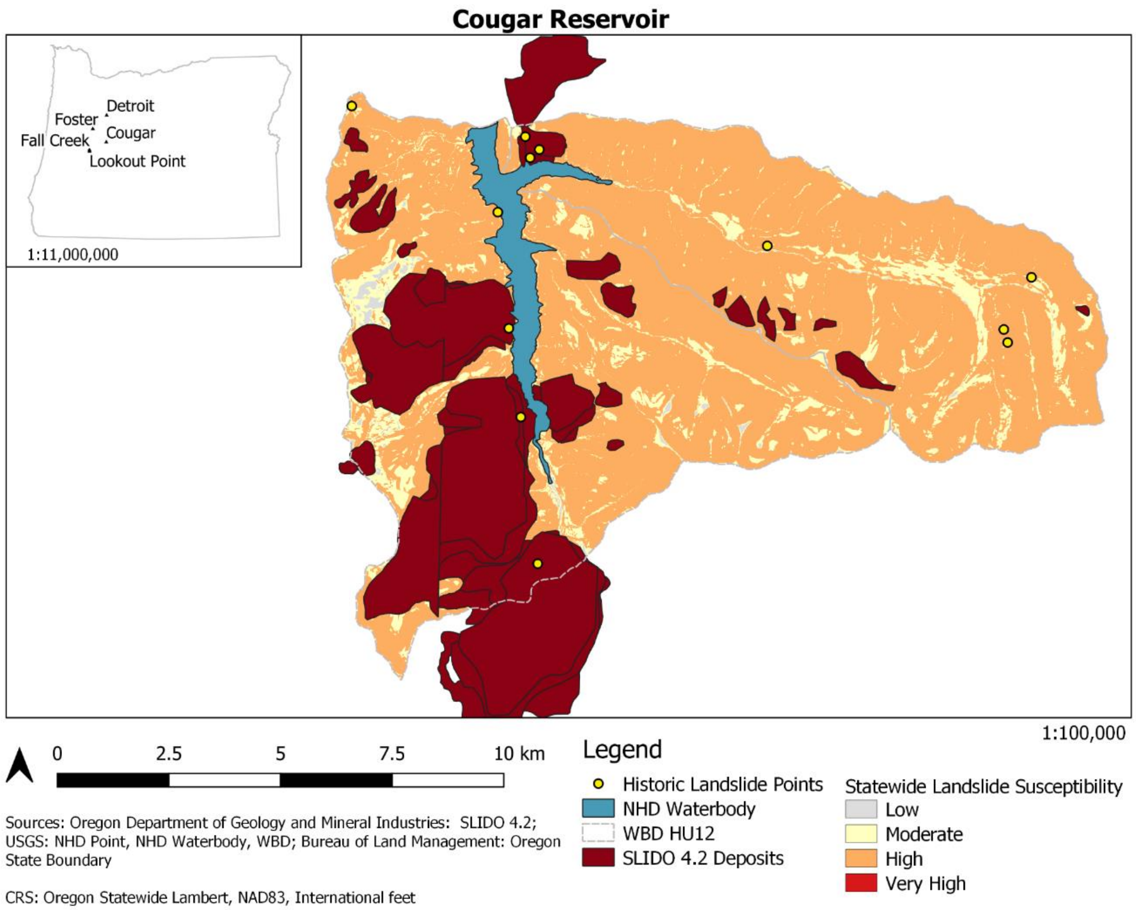
While this operational strategy is not expected to lead to substantial increases in the risk of landslides, it is noteworthy that the hillslopes around the reservoir are highly susceptible to landslides, and that the adjacency of Highway 20 and the community of Foster increase the consequences should a landslide occur. The reservoir hillslopes have already experienced multiple historical landslides, including several adjacent to the highway, and landslide deposits have been documented along the shoreline (Figure 4). Despite this relatively high risk of landslides at Foster reservoir, the expectation of a limited effect of the proposed operational change (delayed refill) on elevating landslide risk and the trapping of the eroded sediments in the conservation pool lead to this measure being placed in the *no appreciable risk* category.

Figure 4. Landslide susceptibility at Foster reservoir. Data source: DOGAMI (2020). See Appendix 1 for summary of methods for assessing landslide susceptibility.



Limited refill and early drawdown at Cougar (McK1 and McK2). These two operational measures are unlikely to increase the instability of reservoir sediments as they will not draw the reservoir down faster or deeper than is scheduled in the rule curve. Cougar reservoir (Figure 5) has documented landslide deposits adjacent to the shoreline, most of the hillslopes are mapped as high susceptibility, and a small portion (~0.3 miles) of the shoreline was burned by the Holiday Farm fire in 2020. However, while landslide risk at Cougar is not low, it is not expected that the proposed measures would result in elevating that risk.

Figure 5. Landslide susceptibility at Cougar reservoir. Data source: DOGAMI (2020). See Appendix 1 for summary of methods for assessing landslide susceptibility.



Supporting the assessment of low landslide risk, a prior drawdown of the reservoir that occurred in 2002 for construction of the temperature control tower (Figure 6) did not appear to appreciably affect the landslide deposits. During that drawdown event, some vertical and

lateral erosion did occur, resulting in elevated suspended sediment downstream. In addition, the drawdown also exposed and eroded former landslide deposits that had been submerged under the reservoir, producing elevated suspended sediment concentrations (G. Grant, personal communication). However, while downstream habitats were impacted by the intrusion of fine sediments into spawning gravels (Grant et al 2015), areas of substantial deposition downstream were not documented. As a result, this measure is rated as *no appreciable risk* for elevated sediment instability.

Figure 6. Vertical and lateral erosion at Cougar reservoir during the 2002 drawdown (Source G. Grant, USFS)**.**

<u>Deep drawdown at Cougar (McK 3).</u> This measure proposes to draw down Cougar reservoir 27’ below normal pool in November to December. Similar to the proposal for delayed refill at Foster (SS5), some additional minor erosion may occur in the upper portions of the reservoir as a result of the water surface slope approaching the valley slope (i.e. part of the reservoir acting like a river) during months with elevated rainfall. However, it is expected that the majority of the eroded sediment would be trapped in the remaining pool near the dam. Similar operations were conducted in December 2012-January 2013 and did not result in elevated suspended sediment beyond background concentrations (Askelson declaration 132). Under the right conditions (if soils are already saturated), the additional 27’ of drawdown could reduce the stability of hillslopes in a reservoir with a history of landsliding. Nearby infrastructure is limited but includes a local road, actively-used campgrounds, and road access to the dam. Mitigation of landslide risk could be achieved by avoiding drawdown in years with high levels of precipitation

in October to December that saturate hillslopes. Thus, while the mobilization of reservoir sediments is unlikely to increase downstream flooding, the potential for the drawdown to increase landslide risk under some circumstances leads to this measure being classified as *minor or mitigatable risk*.

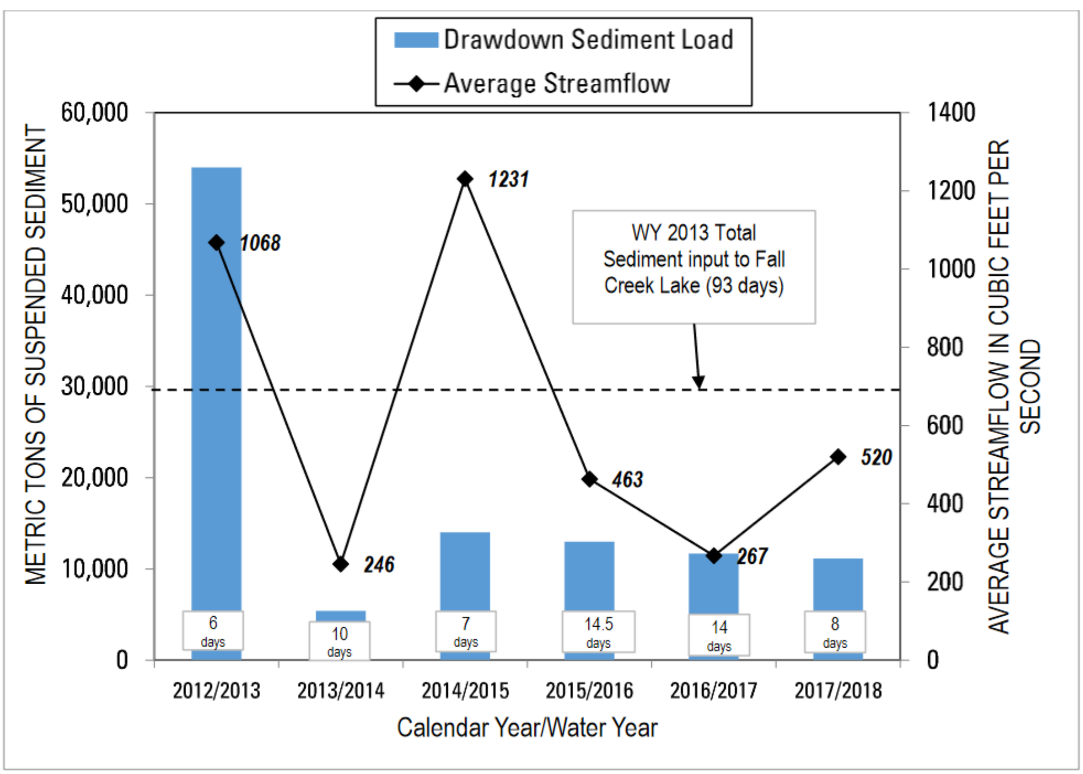
<u>Delayed refill at Cougar (McK4).</u> As a result of delaying refill at Cougar reservoir by three months (from February 01 to May 01), the upper portions of the reservoir will be subject to additional erosion as spring snowmelt and storm events pass through the reservoir. However, like the deep drawdown at Cougar (McK3), eroded sediment is expected to be trapped by the reservoir that is established by the minimum conservation pool. Furthermore, it is not expected that landslide risk would be appreciably elevated by this operation. Thus, this measure is unlikely to result in substantial downstream deposition and thus was rated as *no appreciable risk*.

<u>Deep drawdown at Lookout Point (MFW1).</u> This proposed measure would draft Lookout Point reservoir an additional 75' below the minimum conservation pool during November and December to reduce the depth the fish have to swim to reach the ROs for safe passage. Given that a sizable proportion of the reservoir would be drawn down to the streambed, it is expected that this drawdown would lead to vertical and lateral erosion in the clays and fine sands that comprise the reservoir sediments. This is potentially the first drawdown at Lookout Point since its construction (Askelson declaration 159). Thus, the volumes of sediment eroded during the first year may be substantial but are expected to decrease with each annual drawdown as observed in Fall Creek reservoir (Figure 7).

Deep drawdown has occurred annually at Fall Creek since 2012 to facilitate downstream passage. Results from Fall Creek likely represent a similar set of physical processes that can be expected at Lookout Point since the reservoirs are adjacent and have similar sediment compositions. One relevant finding from the study of Fall Creek operations includes the observation that repeated drawdown operations help maintain a well-defined channel (i.e. thalweg) in the reservoir, rather than the channel laterally migrating across the former

floodplain (Keith and Stratton 2019). This finding is important because having a well-defined channel means that other zones of the reservoir, such as the reservoir margins where landslide deposits may be stored, are not as likely to erode. From a risk perspective, the result of a well-defined channel is a limited volume of sediments eroded and a reduced risk of eroding the toe of landslides. This re-occupation of the well-defined channel likely explains the reduction in suspended sediment observed downstream in subsequent years of drawdown at Fall Creek (Figure 7, Schenk and Bragg 2019). A second relevant finding from the study of Fall Creek drawdowns is the observed deposition of sand in side channels and other low velocity zones downstream of the dam, and that the deposition appears to persist in vegetated areas (Keith 2019). To my knowledge, there is no evidence that this deposition has appreciably impacted flood elevations. However, preliminary data reported by the USGS (Keith 2019) indicated that local deposition of up to 1.6m occurred at one location after the 2016 drawdown of Fall Creek, though depths were generally lower than that and not detectable at the reach scale.

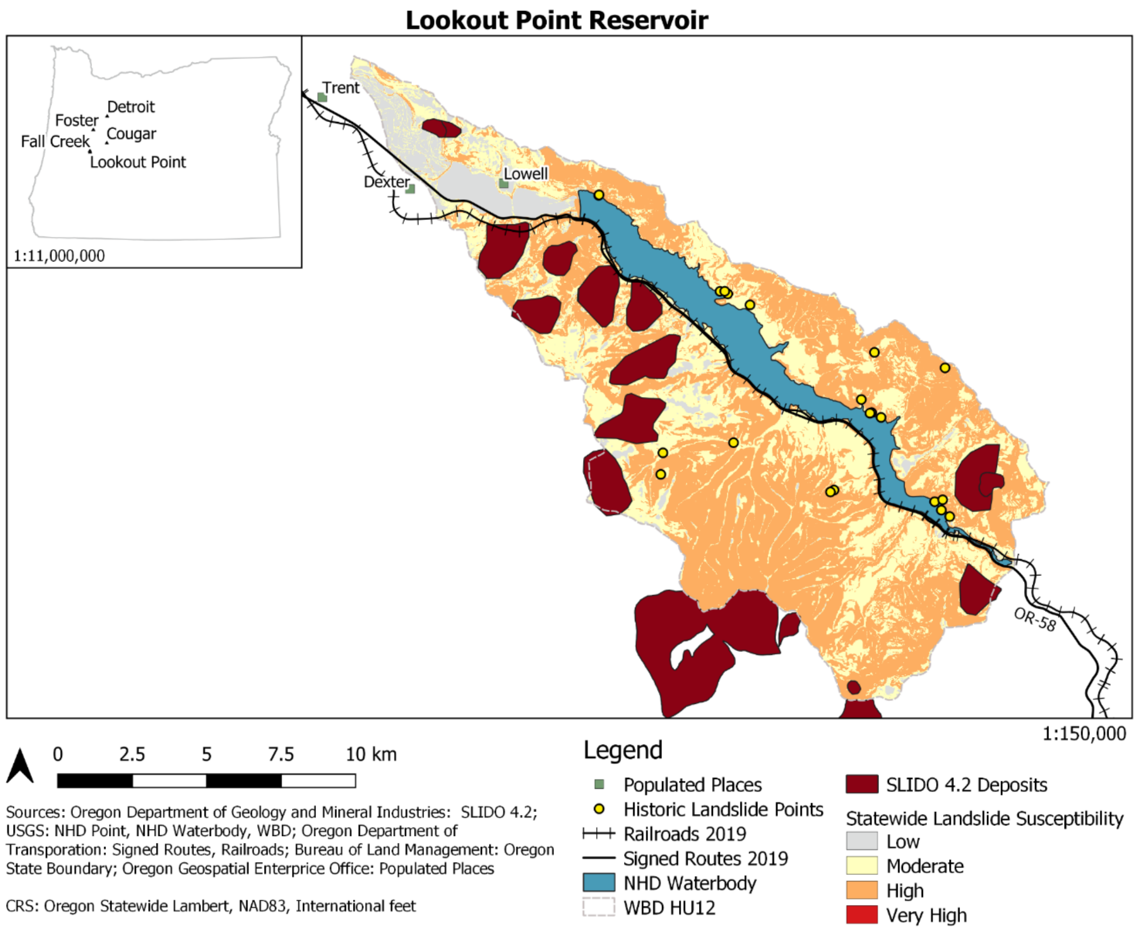
Figure 7. Sediment loads downstream of Fall Creek reservoir during the drawdown period (Source Schenk and Bragg 2019). Note the high loads of sediment reaching the downstream USGS gage during the first year of drawdown, followed by smaller loads in subsequent years.



While it is expected that drawdown at Lookout Point may follow a similar pattern as Fall Creek in mobilizing reservoir sediments, some differences are noteworthy. First, Fall Creek is only lowered to 40’ below minimum conservation pool, whereas Lookout Point would be 75’ below the conservation pool under the proposed operation. In addition, the storage capacity at Lookout Point (443,000 acre-ft at max conservation pool) is nearly four times the storage capacity at Fall Creek (117,800 acre-ft at max conservation pool). The catchment size upstream of the Lookout Point (991 mi^2) is more than five times larger than the catchment above Fall Creek (184 km^2), reflecting a likely larger pool of sediments stored in the reservoir. These factors (lack of prior drawdown, the larger drawdown depth, the larger upstream catchment, and the larger storage capacity of the reservoir) would indicate that more sediment may be mobilized than what was observed at Fall Creek. However, modeling of reservoir erosion for the OMET LOP_04 scenario (Askelson declaration, 159; USACE 2017), found that only 16,300 tons of clays and fine sands may be transported out of Lookout Point during drawdown. For context, it was estimated (Schenk and Bragg 2019, Figure 7) that 55,000 tons of sediment eroded from Fall Creek during the first year of drawdown (2013), with the noted deposition in the channel downstream in 2016. Two factors may explain why model results indicate sediment release at Lookout Point will be lower than what was observed at Fall Creek. First, the model used to develop the 16,300 ton estimate (AdH) does not include algorithms that represent lateral erosion of reservoir sediments (or landslides) and thus likely represents an underestimate of the amount of material available for erosion. Second, the ROs at Lookout Point are located at a higher elevation on the dam than at Fall Creek, which will result in the Lookout Point reservoir trapping some of the mobilized sediment. When Fall Creek reservoir is at the invert elevation of the ROs (670’), the remaining storage is virtually zero, whereas when Lookout Point reservoir is at the invert elevation of the ROs (724’), the remaining storage is 4960 acre-feet (= 1% of conservation pool and the equivalent of ~2500 Olympic-sized pools). As a result, Lookout Point will have a residual pool to trap some of the mobilized sediment. Furthermore, some proportion of the clay and sands transported out of Lookout Point reservoir will be deposited in Dexter reservoir, further reducing potential for flooding in the Middle Fork Willamette below Dexter. In summary, with respect to stored reservoir sediments, while drawdown at Lookout

Point is likely to mobilize more sediment than at Fall Creek, some proportion of that sediment will be trapped in Lookout Point and Dexter reservoirs, reducing potential for flood impacts downstream.

Figure 8. Landslide susceptibility at Lookout Point reservoir. Data source: DOGAMI (2020). See Appendix 1 for summary of methods for assessing landslide susceptibility.



With respect to landsliding, historical landslides have occurred in the reservoir and landslide susceptibility is mapped as high to moderate for the adjacent hillslopes (Figure 8). While the landslide susceptibility at Lookout Point is not the highest of all of the Cascade reservoirs, the deeper drawdown represents some increased risk of landsliding, particularly near the dam and in a year with large amount of rainfall in November and December when the hillslopes may already be nearing saturation during the time of drawdown. Given the near location of key infrastructure (OR-58, railroad) and the history of landsliding at Lookout Point in

response to valley ponding (Howell 1952), this particular risk requires further investigation. Thus, given the uncertainty surrounding how much stored sediment may be transported downstream, the uncertainty in how deep drawdown may impact landslide susceptibility, and the local infrastructure at risk should landslides occur, this measure has been categorized as having *high likelihood or consequence risk*. The risk category could be reduced to *minor or mitigatable risk* with additional information:

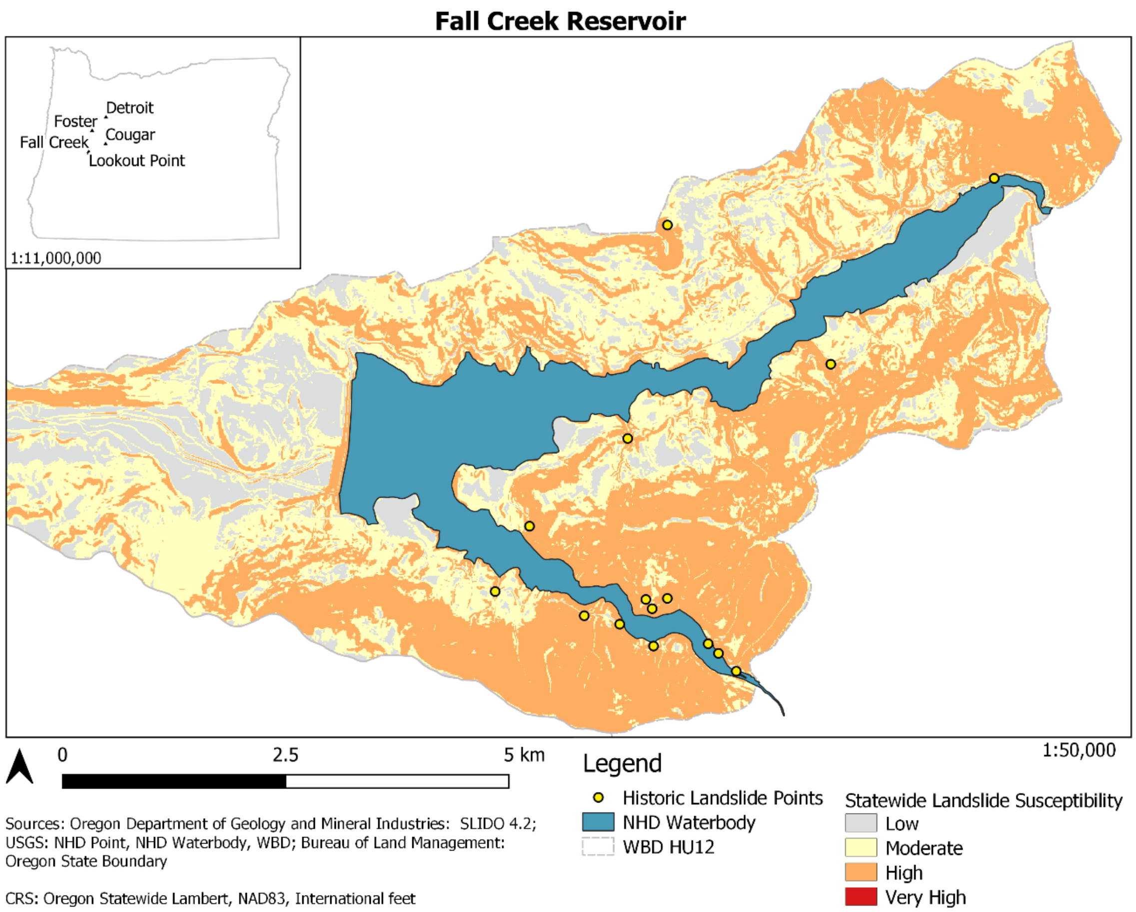
1) Results from hillslope stability models that characterize the local-scale hillslope-reservoir hydrogeology at Lookout Point will clarify what portions of the hillslope are hydraulically-connected to the reservoir, whether, where, and when deep drawdown may contribute to landsliding, and what infrastructure may be at risk should landsliding occur; and

2) From a life safety perspective, a GIS-based geomorphic analysis of the channel downstream of Dexter Dam should be adequate to identify likely locations of deposition for reservoir sediments and evaluate whether that deposition would appreciably affect flooding. Additional reservoir-river hydrodynamic modeling would only be warranted if substantial landslide risk was found and/or the geomorphic analysis indicates substantial flood risk may result a sediment pulse from Lookout Point.

<u>Extended drawdown at Fall Creek (MFW9).</u> This proposed measure would extend the deep drawdown of Fall Creek through January 15 instead of ending in early December. As discussed above, the drawdown operations at Fall Creek for juvenile fish passage are representative of a case where drawdown has produced vertical and lateral erosion, the rates of which have declined over time. A longer duration of holding the reservoir at the streambed would likely increase sediment export (Keith 2019) associated with erosive winter events, though the volumes of sediment are not likely to be large, given that the reservoir appears to maintain its well-defined channel. With respect to landslides, unlike many of the other Cascade reservoirs, the susceptibility to and consequences of landslides in Fall Creek reservoir are not high (Figure 9). At Fall Creek reservoir, the landslide susceptibility is generally low to moderate and is discontinuous in space. In addition, while historical landslides have occurred in the basin, they were upslope or in the upstream portion of the reservoir. Currently, there are no documented

landslide deposits and there is minimal infrastructure that would be impacted by a landslide should one occur. Thus, based on the expectation that the operation is unlikely to erode large volumes of sediment or trigger hillslope instability, this measure is rated as having *no appreciable risk*.

Figure 9. Landslide susceptibility at Fall Creek reservoir. Data source: DOGAMI (2020). See Appendix 1 for summary of methods for assessing landslide susceptibility.



3.2.3 *Loss of flood control capability*

The loss of flood control capability was analyzed by applying principles from dam safety risk assessment (DeNeale et al. 2019). Of the common key failure mechanisms that could lead to loss of flood control capability (i.e. overtopping, internal erosion, sliding, overturning, overstressing, outlet failure), only impacts to the outlet structures that regulate releases were determined to be worthy of further consideration. That is, I did not consider catastrophic overtopping during a high flow event or complete failure of the dam to be within the realm of possible responses to the proposed operational measures. For example, while complete failure of the dam due to internal erosion (i.e. piping) from seepage has contributed to the failure at earthen dams during rapid drawdown, it is expected that the USACE anticipates these processes and will not conduct operations that put their earthen structures (Cottage Grove, Fern Ridge, Green Peter, Hills Creek, and Lookout Point) at risk. Regarding catastrophic overtopping, the large capacity of the spillways and expertise of the USACE in flood operations makes this scenario extremely unlikely, even in the event of a turbine or gate failure. Thus, the following analysis is based on what I perceive to be the most likely outcome of a hydromechanical failure: uncontrolled water releases through a failed outlet.

The increased and varied use of the gates and other outlet works may reduce the reliability of mechanical, electrical, and conveyance systems that regulate releases. Increased use is known to subject hydromechanical equipment, including gates, turbines, spillways, and conduits, to increased wear and tear. General examples of types of impacts associated with more frequent and longer duration use of hydromechanical equipment include:

- Random stops and starts on hydropower equipment can reduce on-demand reliability, where on-demand reliability is a measure of how likely equipment will function as intended during critical operation periods. Stops and starts also increase operation and maintenance needs. Multiple papers (See Yang et al. 2018 for review), have illustrated how the on/off grid demand of alternative power generation can cause severe wear and tear of components at hydropower plants. While I was unable to find specific on-demand failure rates or service life reductions for increased use, the US Bureau of Reclamation (USBR 2041) reported that start/stop

costs for hydrogenation equipment vary between $275-$411 per start/stop, which includes costs associated with increased maintenance, accelerated degradation of the equipment, and reduced efficiency. As pointed out by Piaskowski (Piaskowski declaration 26), the proposed measures (NS2, SS4, McK5) associated with turning turbines off at night for downstream passage can contribute to deterioration of shear pins on turbines. Shear pins hold parts (e.g. the wicket) of the turbine together. If a mechanical overload (of force) occurs, often with rapidly-changing reservoir operations, shear pins are designed to break to avoid damage to more critical parts of the turbine. However, undetected failures of shear pins have led to the cascading failure of more significant parts of the turbine. Other components of the hydromechanical equipment (e.g. bearings, runners, etc.) may also be subject to wear and tear from the start/stop cycling of equipment (Yang et al. 2018).

- For operations that involve passing sediment (e.g. deep drawdown at Lookout Point), abrasion of gates and outlet structures can occur during times when high sediment loads are released. As discussed below, degradation of concrete over time can lead to substantial maintenance issues and outlet failure. In addition, it is expected that increased use of ROs will require increased maintenance to remove debris;
- As noted in Askelson's declaration, extending deep drawdown at Fall Creek (SS5) will subject the upstream dam face to prolonged erosion and wave action. This issue was already noted during at 2014 Periodic Risk Assessment (Askelson declaration, 193), and while the dam is not immediately at risk, extending the drawdown during winter months increases potential for erosion at the upstream face of the dam.
- The Supervisory Control and Data Acquisition (SCADA) systems of instrumentation and computers used to monitor and operate the outlet works on dams are known to frequently fail, [redacted]

[redacted]

On the other hand, some measures may increase the on-demand reliability for RO gates that are not regularly operated (e.g. Lower ROs at Detroit). Reliability modeling indicates that the more a gate is operated, the higher the reliability and the lower the probability of failure, even with aging equipment. Gate systems that are tested or operated at intervals from monthly to daily frequencies tend to have low on-demand failure probabilities (Ballard and Lewin 2004). Thus, increased use can both increase wear and tear over time, similar to putting more miles on a car, while also increase reliability of gates that are not regularly operated, similar to how driving a car regularly keeps seals and gaskets lubricated, a battery charged, and high awareness of equipment condition.

Even for measures that increase wear and tear, they generally are not likely to produce catastrophic failure or reduce life safety. Dams and reservoirs typically have adequate redundancy and flexibility to prevent complete loss of flood control capability. [redacted] However, while catastrophic failure is not likely to occur, increased and varied use will likely accelerate the timeline for maintenance and replacement and increase the need for monitoring. The more frequent repair and maintenance schedule will impact the ability of the reservoirs to achieve the project objectives and to conduct other operations (e.g. temperature management, meet minimum flows). Increasing the frequency of maintenance of these structures can impact operations of the reservoirs to a similar extent as climate change (Tullos et al. 2020). Furthermore, mitigating these risks requires a robust and expensive program for monitoring and maintaining our

nation's aging infrastructure, a program that has seen a steady decline in funding over decades (Riley 2014).

However, while wear and tear on an individual part is not likely to lead to complete loss of flood control capability, if not addressed, increased wear and tear can contribute to the failures that do impact life safety. Catastrophic incidents (DeNeale et al. 2019 Appendix A, ASDSO 2021) tend to occur as a result of unusual combinations of operations, and are ultimately attributable to human factors. It is the accumulation of many small, but interacting, incidents that leads to catastrophic failure at dams. The failure of the service and emergency spillways at Oroville Dam (CA) is the most recent example of such a compound failure. While the public's image of the failure was broken concrete on the primary spillway, the long list of contributing factors included decades' worth of accumulated design, construction, and maintenance failures. These failures included deficient design of concrete drains that required repeated repairs, the construction of the spillway on unconsolidated rock, and inadequacy of energy dissipation and erosion protection for the emergency spillway (IFT 2018). Importantly, the failure was also produced by a number of human failures, including lack of communication and consultation with the designer during construction, overconfidence, complacency, and power struggles within the office that managed the dam, and the reactive culture around dam safety at the national scale. Among other things, avoiding these kinds of catastrophic failures is accomplished by regular inspection and maintenance of infrastructure, as well as adequate priority on and resources for responding to identified maintenance issues.

The USACE provided periodic inspection reports for some (i.e. Fall Creek 2019, Lookout Point 2017 and 2019, Detroit 2016, 2019, and 2020, Cougar 2017) of the projects impacted by the proposed measures. The reports generally provided detailed notes on the condition of various parts of the hydromechanical equipment, documented repairs that have been made, and made recommendations on issues that should be addressed. In addition, two of the reports were extracted from a 2017 assessment of ROs across the basin, and these reports included results of hydraulic modeling to evaluate downstream flood risk should the ROs fail at Detroit or Lookout Point. Because I requested inspection reports for ROs specifically, I did not receive reports for all of the dams because they either do not have RO (Big Cliff, Foster, Dexter) or

because no RO operations are proposed (Green Peter). I also did not receive any information regarding the condition of non-RO components of any of the dams. In addition, the report for Cougar was several years old. As a result, my assessment of the potential risks focuses on ROs and risks associated with other outlet works are not considered.

Regulating Outlets are important [redacted] parts of the WVP dams, and several of the proposed measures are expected to result in increasing the frequency and duration of their use. [redacted]

This quote was extracted from a comprehensive assessment of ROs for all NWP projects that was undertaken in 2017. Two of the RO assessment reports (Lookout Point, Detroit) provided by the Defendants appear to be extracted from that 2017 document. However, I was unable to find a complete copy of that report to understand RO conditions at other dams, or any information regarding responses to the findings in that report. [redacted]

[redacted].

[redacted]

[redacted]

[redacted]

[redacted]

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[redacted]

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7. Appendices

Appendix 1. Details of landslide location and susceptibility mapping

SLIDO is an inventory of landslides in Oregon from published maps represented as historical center points, deposits, scarp flanks, and scarps (DOGAMI, 2020). Only the center point and deposit polygons are in these reservoir area maps as the scarps and scarp flanks are only present in the dataset in the Detroit Reservoir area and are too small to be seen at the scale of the whole reservoir. The landslide deposit dates range from 1949 to 2020 (DOGAMI, 2020; Burns and Madin, 2009), and historical landslide points are estimated to have occurred between 1928 and 2018 (DOGAMI, 2020).

Starting with the 4.x versions, landslide susceptibility was added to SLIDO as three components: detailed deep and shallow landslide susceptibility (1:8,000, 3-meter cells), and statewide landslide susceptibility overview (1:500,000, raster with 10-meter cells) (DOGAMI, 2020, Burn et al. 2016). Only the statewide dataset is present in the reservoir areas. The statewide landslide susceptibility dataset was derived as four classes, Low, Moderate, High and Very High, from a combination of geology, existing mapped landslides, and slopes calculated from Oregon LiDAR Consortium elevations, where available, or USGS NED elevation (DOGAMI, 2020, Burns et al. 2016). LiDAR data was collected from 2000 to 2016 (DOGAMI, 2020).

Appendix 2. Descriptions of proposed measures and relationships to prior modeling results (OMET 2012).

Table A2:1. Proposed measures for the North Santiam Basin.

Plaintiffs' proposed measures					
ID	Basin	Short description	Long description	Type of measure	Scenario evaluated in 2012 USACE
NS1	North Santiam	Detroit: Drawdown (Nov-Dec)	Draw down Detroit Reservoir below min cons. pool (1450') by Nov 1 and maintain below 1450' through Dec. 1, use lower RO during that time for temperature control.	drawdown	Similar to DET_04, but not as deep or as long
NS2		Detroit: Regulating outlets at night	From Nov 1 through Feb. 1, use upper RO and turn off turbines during the hours of 4 pm to 8 am.	same flow, different outlet	DET_06
NS3		Detroit: 1/2 spillway flows at night	As soon as Detroit refills to 1543', operate the spillway so that at least one-half of the total project discharge (as measured below Big Cliff) is released from 6 pm to 6 am daily for thirty consecutive days.	same flow, different outlet	Similar to DET_03
NS4		Detroit: Use turbines for total dissolved gas	During other times, manage discharge at Detroit to reduce TDG below Big Cliff.	same flow, different outlet	
NS5		Big Cliff: Spread spill	Spread spill across gates at Big Cliff to the max extent possible to reduce TDG	same flow, different outlet	
NS6		Big Cliff: Use turbines for total dissolved gas	When spawning and incubation below Big Cliff is occurring, prohibit operations that would result in TDG exceeding the state standard in spawning areas unless necessary for flood control	same flow, different outlet	

Table A2:1. Proposed measures for the South Santiam Basin.

Plaintiffs' proposed measures					
ID	Basin	Short description	Long description	Type of measure	Scenario evaluated in 2012 USACE
SS1	South Santiam	Green Peter: spillway	After outplanting begins, once the reservoir reaches 970' the following spring, operate the spillway on a 24-hour basis for thirty days at a rate that is at least one-half of the daily average outflow, and open the upper fish horn during that time.	same flow, different outlet	
SS2		Green Peter: Use of fish horn	During fall drawdown, when the reservoir elevation is within 40' of a fish horn, open the fish horn until the reservoir drops below it.	same flow, different outlet	
SS3		Green Peter: Temperature operations	Conduct operations to improve downstream water temperatures and meet flow	same flow, different outlet	
SS4		Foster: Spillway operations	Operate the spillway and turn turbines off Oct 15-Dec. 15 for the hours of 4 pm to 8 am and March 1-June 15 for the hours of 7 pm to 7 am.	same flow, different outlet	
SS5		Foster: Delayed refill	Maintain Foster Reservoir at minimum conservation pool through May 15.	modified refill	FOS_01
SS6		Foster: Temperature operations	Conduct operations to meet water temperature targets	same flow, different outlet	

Table A2:3. Proposed measures for the South Fork McKenzie Basin.

Plaintiffs' proposed measures					
ID	Basin	Short description	Long description	Type of measure	Scenario evaluated in 2012 USACE
McK1	South Fork McKenzie	Cougar: Reduce max refill	Limit refill of reservoir to 1600’	modified refill	
McK2		Cougar: Early drawdown	Drop reservoir to 1570’ by Sept. 1.	drawdown	
McK3		Cougar: Early and deeper drawdown with outlet change	Drop reservoir to 1505’ by Nov 15 and hold there until Dec. 15. Turn off turbines when the reservoir reaches minimum conservation pool (1532’).	drawdown + same flow, different outlet	Similar to CGR_-3b but deeper and shorter; Similar to CGR_03 but slightly deeper and shorter
McK4		Cougar: Delay refill	Maintain the reservoir at minimum conservation pool until May 1 unless the technical advisory team recommends beginning refill prior to that date based on current hydrologic data.	modified refill	similar to CGR_05, but CGR_05 included prioritization of ROs
McK5		Cougar: Regulating outlets during spring	Turn off turbines from 6 pm to 7 am and operate RO Feb. 15-June 1.	same flow, different oulet	CGR_01 (simulated earlier start date)

Table A2:4. Proposed measures for the Middle Fork Willamette.

Plaintiffs' proposed measures					
ID	Basin	Short description	Long description	Type of measure	Scenario evaluated in 2012 USACE
MFW1	Middle Fork Willamette	Lookout Point: Early and deeper drawdown	Begin reservoir drawdown Aug 1, lower the reservoir to 750’ by Nov. 15 and hold there until Dec. 15.	drawdown	Similar to LOP_04 but slightly deeper and shorter
MFW2		Lookout Point: Regulating outlets for temperature	Begin using RO Aug 15 for temperature control	same flow, different outlet	LOP_01 (but simulated much longer period)
MFW3		Lookout Point: Regulating outlets during drawdown	Turn off turbines when reservoir reaches minimum conservation pool (825’).	same flow, different outlet	LOP_02
MFW4		Lookout Point: Prioritize refill and spring spill	Prioritize refill of Lookout Point Reservoir to maximize opportunity for spill in spring.	Modified refill	
MFW5		Lookout Point: Ungated spring spill	When reservoir reaches 889’ in spring (mid-March), conduct free, ungated spill for 2-4 weeks. Maintain reservoir below 911’ during this operation.	same flow, different outlet	
MFW6		Dexter: Fall spill	During the fall drawdown operation at Lookout Point, conduct spill and turn turbines off at Dexter Dam from 4 pm to 8 am.	same flow, different outlet	
MFW7		Dexter: Spring spill	During the spring spill operation at Lookout Point, conduct spill and turn turbines off at Dexter Dam from 7 pm to 7 am.	same flow, different outlet	
MFW8		Dexter: Spread spill	Spread spill across gates at Dexter Dam to reduce TDG	same flow, different outlet	
MFW9		Fall Creek: Extended drawdown	Conduct the deep drawdown at Fall Creek similar to prior years but extend the dates from Dec. 1 through Jan. 15.	drawdown	FAL_01 but with shorter duration
MFW10		Fall Creek: Regulating outlets for lower spring and summer pool	Operate ROs to maintain reservoir at 728’ from Feb. 15 to April 15	Increase spring releases	